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Systems Analysis Department Annual Progress Report 1985

Edited by P.E. Grohnheit, H. Larsen, N.K. Vestergaard

Risø National Laboratory, DK-4000 Roskilde, Denmark
February 1986

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SYSTEMS ANALYSIS DEPARTMENT
Annual Progress Report 1985

Edited by
P.E. Grohnheit
H. Larsen
N.K. Vestergaard

Abstract. The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1985. The activities may be classified as energy systems analysis and risk and reliability analysis. The report includes a list of staff members.

INIS-Descriptors: DENMARK; RISOE NATIONAL LABORATORY; POWER DEMAND; POWER GENERATION; ECONOMIC ANALYSIS; ENERGY ANALYSIS; PLANNING; RESEARCH PROGRAMS; PROBABILITY; RISK ASSESSMENT; RELIABILITY; OFFSHORE OPERATIONS; OFFSHORE PLATFORMS.

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1. INTRODUCTION

The activities of the Systems Analysis Department in 1985 covered a wide range of subjects such as the development of methods and tools, risk assessment, energy planning, and technology assessment. The various tasks undertaken are carried out either as basic R&D studies or under contract with different organisations in Denmark and abroad, or as consultants for industry.

The Systems Analysis Department was established January 1985 by joining the Energy Systems Group (ESG) and the Risk Analysis Group (RAG). The previous activities of these groups have been continued within the new department. Progress Reports 1984 for ESG and RAG were issued as (Ref. 1) and (Ref. 2). In April 1985 a one-day seminar was arranged at Risø presenting the scope of activities of the new department to industry, companies, ministries, etc.

The majority of the studies undertaken by the department involves a close collaboration with Danish and foreign companies, consulting firms, ministries and international organisations, such as the Danish Ministry of Energy, the Danish Energy Agency, the National Agency of Environmental Protection, the Nordic Council of Ministers and the Commission of the European Communities.

The research and development activities in 1985 involved three ongoing postgraduate research projects: One concerns unwanted and runaway chemical reactions in the chemical process industries. Another project deals with the development of an energy-rationing model for acute energy shortages. Finally, a postgraduate research project deals with energy supply technologies for developing countries.

The research and development activities of the Energy Systems Group have included work on the macrosectoral model HERMES as well as work on the development of a European version of the Danish Energy System model DES; both are carried out in connection with the third energy-modelling programme of the Commission of the European Communities about to start up. Work has continued on the development of methods that allow uncertainties to be incorporated in the economic calculations for energy technologies. The Danish Energy Systems model DES is continuously being modified and improved for Danish purposes. Finally, a simulation model has been developed for the simulation of combined collective energy systems.

The Energy Systems Group has been involved in Danish energy planning for many years. In 1985 work has been started on a new Energy plan for Denmark to be published in 1986 by the Danish Ministry of Energy. The work involves the running of the DES-model and the participation in a number of working groups. A major study has been carried out for the Ministry of Energy on the development of a technical-economic model for energy consumption in industry. Furthermore, a number of small projects have been carried out concerning wind energy. By the end of 1985 work has been initiated on a new major project in the oil and gas area concerning the development of technical and economic models to be used by the Danish authorities in connection with future explorations and field developments in the North Sea.

The research and development activities of the Risk Analysis Group have included work on a Nordic project concerning probabilistic risk assessment and licensing, carried out within the research program of the Nordic Liaison Committee for Atomic Energy. The group participated in the European Reliability Exercise with the purpose of performing a common cause failure analysis of the steam generator water feeding systems of the new German PWR power plant Grohnde. Furthermore, work has been carried out concerning the improvement and updating of the RIKKE-package, which is an automatic fault-tree construction program. Finally, work has been initiated on gas-dispersion and plume formation models, as part of a new consequence management program.

A number of projects carried out under contract have been completed. Safety analyses of offshore oil and gas production installations have been carried out for Danish and foreign companies. Risk assessment studies have been carried out for a number of chemical industries in Denmark. Furthermore, the Group participated in a risk analysis of the alternative crossings over the Great Belt. Finally, a major project has been completed concerning the implementation of the Seveso directive on risks in connection with certain industrial activities in Denmark.

During the year a guest researcher from the Electric power research institute of Mexico has visited the department for 5 months and a guest researcher from Rutherford Appleton Laboratory in the U.K. has visited the department for 1 month. Members of the department have participated in and presented papers at various international conferences. Finally, one member of the department has visited the department of Energy in Zambia for two months.

2. RISK AND RELIABILITY MODELS

The modelling activities of the Risk Analysis Group cover a wide variety of developments of methods and tools for risk and reliability analysis. Probabilistic risk assessment, expert systems for use in emergency control and common cause failures are among the subjects dealt with.

The RIKKE-package for automatic fault-tree construction is continually being improved and work on a new consequence management program has been initiated.

2.1. Risk assessment

Risø has participated in a couple of international projects with the purpose of verifying and developing methods and tools intended for the assessment and management of risks.

The first series of projects has been carried out within the research programmes sponsored by the Nordic Liaison Committee for Atomic Energy (NKA). The last project, sponsored by Joint Research Centre of Ispra, concerns a feasibility study of an expert system intended for use in emergency control.

The project "Probabilistic Risk Assessment and Licensing" was performed within the NKA research programme 1981-85. The main report (Ref. 3) summarizing the results of the project was edited and printed in 1985. The scope of the project was to verify and develop methods for failure identification, accident sequence modelling and reliability calculation.

As a continuation of this project a review of the results with respect to non-nuclear applications has been carried out in close contact with industry, consultants and authorities. The work has been documented in a report, showing that the methods used in nuclear applications are valuable for non-nuclear applications as well. It noted also that to fulfil the requirements in non-nuclear applications, other sources of information are needed concerning methods for consequence modelling.

A project "Risk Analysis" within the NKA research programme 1985-89 was started with the aim of studying treatment of common cause failures, human errors and uncertainties in risk analyses in order to cope with the completeness question. The first phase of the project concerned a review of some failure reports contained in the Swedish ATV data base with the purpose of identifying common cause candidates. In the next phase, estimation of reliability parameters based on the findings will be subjects of analysis using various methods.

The study of expert systems for use in emergency control has been carried out in collaboration with Risø's Electronics Department. The project share taken by the Risk Analysis Group will be described briefly.

Ten recent Danish accidents were selected as a basis, all characteristed by the aspects they had in common: some kind of pollution to the environment or other threat to the public. The cases selected were then studied to find actual as well as potential information needs for such situations. As a next step a group of experienced fire officers was consulted for an interview about their views on the information problem and their expectations of future developments.

The following types of information were identified as the most important:

- updated status information on road conditions, water supplies, sewer systems, hospital capacities etc.
- specific data from knowledge centers concerning chemical characteristics, first aid principles, suggested procedures for fire fighting etc. depending on actual chemical, type of plant or container and actual situation parameters: time, weather, district type etc.
- risk analysis presented as an on-line service, or as tabulated risk comparisons, ranking for instance the main plant items of an oil refinery.

The present situation is one in which information in the first group exists, but data have to be collected bit by bit as the need arises, and some sources are not accessible outside working hours.

The next class of information exists only partly, for instance, as the Danish set of chemical emergency cards, but the communication today depends entirely on the proper key word. Much valuable information is useless as long as a specific identification name is lacking.

The third class of information is supposed to have a large potential use, but it is not very clear in which format such information should be presented. However, the case study shows that fire officers often have to make decisions involving risk comparisons that are very weakly based.

2.2. European reliability benchmark exercise on common cause failures

An European cooperation was initiated with the Reliability Benchmark Exercise (RBE). The project was described in the annual report from RAG for 1984 (Ref. 2) and the final report has now been published (Ref. 4). The cooperation will be continued over the period 1985-1987 in three new benchmark exercises on: Common cause failures, human errors, and integrated event sequence analysis.

The first of these, on common cause failures (CCF), was started this year, the CCF-RBE, and the exercise is planned to be finished primo 1986. In total eleven teams from Belgium, Denmark, France, Germany, Italy, Sweden, UK and USA participate in the exercise.

The objectives of the exercise have been defined as follows:

- to achieve a better understanding of available methods and procedures (state of the art);
- to contribute to the establishment of procedures for the identification of potential sources of CCF's;
- to agree on terminology and definitions;
- to clarify objectives and boundaries of qualitative and quantitative methods of analysis;
- to assess methods for quantifying CCF occurrences on field data, experts' judgements etc.;
- to assess methods for quantifying CCF effects in probabilistic safety analyses (PSA), when events and data are assumed to be known.

The system to be analysed from the point of view of CFF's is the steam generator water-feeding systems at the new German PWR Grohnde. The system condition assumed is the emergency power mode. The first working phase was finished medio 1985 and the work done by Risø's team has been reported. In the following the methods used are summarized. The terms of reference for the CCF-RBE are described in detail in (Ref. 5).

As a first step in the selection of common cause failure data, a study was conducted to determine the susceptibilities of the different components (basic events) to several causes which are common to some of them. As a result of this study, the basic events of the fault tree were allocated in different groups. This grouping has been done according to component types, failure models, physical location and maintenance procedures, since these are the primary factors influencing the occurrence of common cause failures.

Once the basic events were allocated in groups, the next step was to estimate the actual probability that a common cause will cause a certain number of the potential components to fail. This estimate was made on the basis of the binomial failure rate model.

The quantitative analysis was made using both the Monte Carlo simulation program MOCARE and the analytical program FAUNET. These codes have been developed at Risø and they were both modified in order to take common cause failure into account. Both of the codes use the same input data. A new option for simulation in MOCARE was developed for the purpose of a simple and fast simulation of systems with CCF'.

After simulation of all the faults, the system is analysed for failure based upon the system failure conditions as specified either by means of the minimal cutsets or - as in this analysis - by means of the fault tree for the system. The prescribed number of trials are executed, and afterwards the probability of failure of the system is calculated on the outcome of the simulation performed.

The Monte Carlo simulation program MOCARE in principle considers all possible combinations of common cause - and independent failures. However, due to CPU-time limitations, only approx 80 different cutsets could be simulated out of a total o 4.3 mio. Although these probably are the most important ones, the limitation of their covering will give rise to a somewhat unknown uncertainty. However, the result agreed in this case with the analytical calculation within the statistical uncertainty.

The FAUNET program produces the cutsets of a given fault tree in condensed form, using complex events, each comprising certain combinations of the basic fault-tree events.

After automatic production or decomposed minimal cutsets, each minimal cutset is analysed separately with respect to CCF's. If more than two faults in the cutset are found simultaneously for any cause in the CCF data file, the increase in the system unavailability, due to CCF's from this cutset is calculated based on the CCF data file probabilities.

In the FAUNET program, the probabilities in the CCF data are ad-adjusted to account for all possible combinations of independent and CCF failures in a given common cause influenced cutset. The probabilities for any fault in the cutset not caused by common causes are taken as the independent failure rates.

The program is made in such a way that cases in which more than one common cause leads to the occurrence of more than one fault in a cutset, will be accounted for. For instance, if the first and third fault in a cutset can be caused by one common cause and the fourth, fifth and sixth by another.

After analysis of all of the cutsets, the total increase in system unavailability due to CCF's is calculated as the sum of the unavailability increases for the individual cutsets.

In addition to the above calculations the program also performs a ranking of the causes in the CCF data file in the order of importance of the causes as far as their influence upon the system unavailability is concerned. Two measures of importance are applied for each common cause: an absolute and a relative one. The analytical program FAUNET can analyse all cutsets if desired, and in this analysis all 4.3 million cutsets were analysed without cutoffs of any kind.

The calculations made by means of Risø's two computer programs MOCARE and FAUNET agreed completely.

2.3. Computer-aided risk analysis

The program package, RIKKE has been developed since 1978 for automatic fault-tree construction.

At the end of 1984 it reached a final state version which has been fixed. In 1985 the work on RIKKE has therefore mainly been concerned with the verification of this final state version.

In april the system has been installed at Imatran Voima Oy. in Finland, and on the behalf of Imatran Voima and other users of the RIKKE package special applications of specific program parts have been delivered. By this, for example, the number of useable terminal and plotter types have been increased.

Two different contacts for further developments on the basis of the system have been established. One contact concern development of customer specific applications of the libraries. The other contact concerns an agreement between European Joint Research Center, Ispra on the development of a new code for fault tree construction and managing.

2.4. Consequence management models

A list of potential program aims has been set up in order to build a program package for supporting consequence management (COMA). From this, actual needs have been identified, such as rapid and easy run programs for calculating toxic plume formation from fires and evaporation, mass flows during blow-down phenomena, etc. It has been decided to build the program package on the basis of independent sub-programs.

The sub-program for calculating plume formation has been developed and has already been used in connection with various projects. Below a short description is given.

Problems involving atmospheric gas dispersion frequently occur when assessing consequences of potential system failures.

Examples are blow-down of a pressurized system, spill of a volatile liquid, cloud formed during a fire etc., where toxic and/or inflammable substances are released to the atmosphere. Within certain concentration limits the possibilities of explosion, intoxication or other invironmental impacts exist, and estimates of ranges and duration of these dangerous conditions are needed. This means modelling the source strength, initial boyancy dominated spread and final passive dispersion. Each of these steps

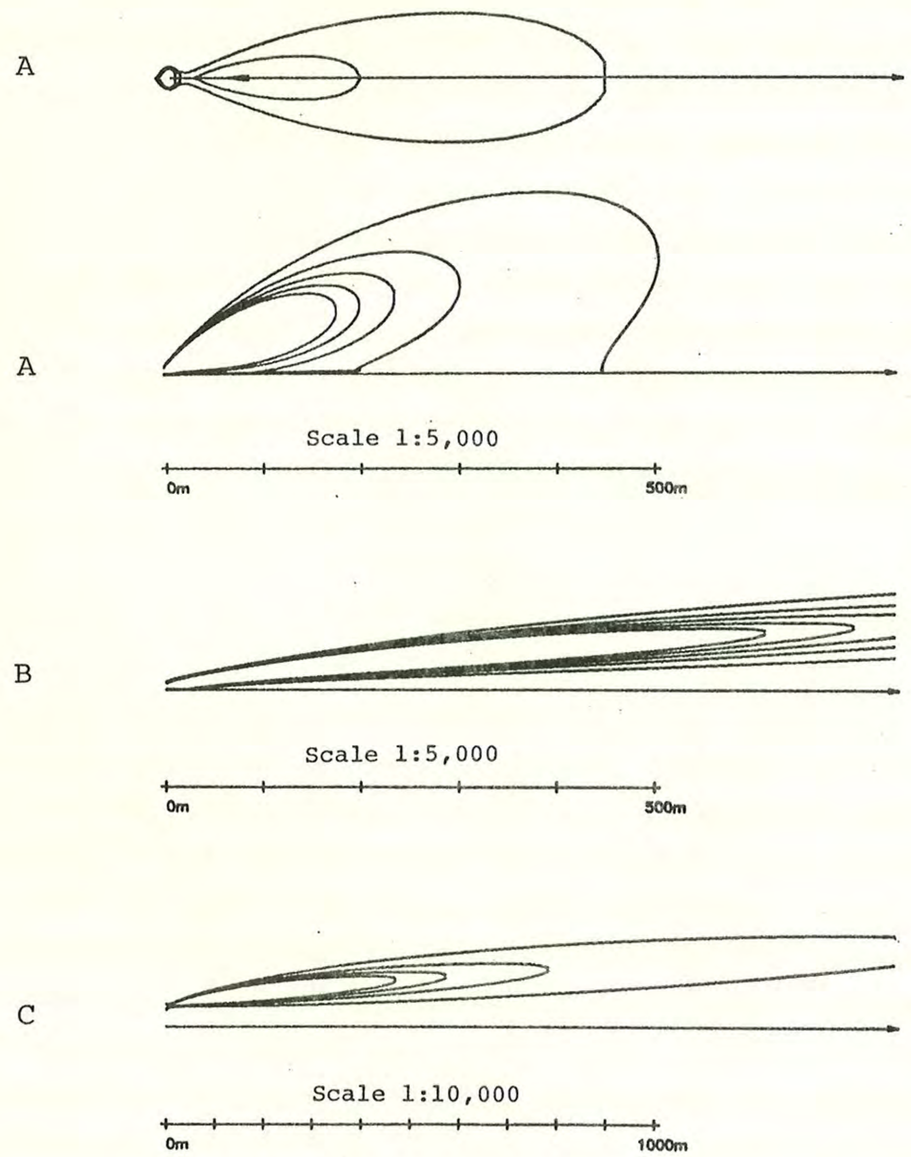

Fig. 2.1. Plume examples.

adds to the number of parameters subject to variation and uncertainty, so that it might be necessary to calculate a large number of scenarios to do a worst-case study, for example. Therefore computationally simple submodels are needed.

The Pasquill-Gifford system is sufficiently accurate for most purposes to fit into the scheme noted above as long as results are carefully interpreted. A simple computer model, based on selected empirical parameters has been developed. Corrections for initial source elevation and extension and thermal lift are included. Outputs are in the form of tables and graphs showing contour curves in vertical and horizontal intersection planes.

In Fig. 2.1 some resulting concentration isopleths are given. A and B illustrates the same release of warm contaminated air, but under different atmospheric conditions (A/B: wind speed: 2.0/5.0 m/s. Pasquill stability class: A/B). C illustrates a plume formed by stack release under "normal" weather conditions.

2.5. Unwanted chemical reactions in the chemical process industry

A Ph.D study concerning unwanted and hazardous chemical reactions in the chemical process industry has been initiated in the summer of 1984.

Unwanted chemical reactions in the chemical process industry is an important area to study because they are the source of many accidents. The circumstances leading to the accidents are very complex involving human errors, insufficient knowledge about chemistry, insufficient process concepts, design and instrumentation, insufficient education of operators etc.

As the first part of the project an accident case stories study was caried out. The second part of the study is a more detailed investigation of an accident which occurred in the Danish chemical process industry.

The project forms a basis for assessing existing methods (risk analysis, laboratory tests) to identify potential unwanted chemical reactions:

- are the methods sufficient
- are the methods used/known by the designers
- how can the methods be improved

The methodology used to answer the question of importance and occurrence of unwanted chemical reactions or uncontrolled chemical reactions was a study of accident case stories, whereby it was possible to get a quantitative presentation of the program. The grouping of the information was made with the intention of getting information about why, how and when accidents occur caused by unwanted chemical reactions.

The results include type of chemicals, initiation mechanism, primary causes (impurities not discovered, insufficient knowledge about chemistry, bad instrumentation, etc.), secondary causes (design error, administrative error, produre error, etc.) and consequences.

In total 190 accident case stories were analysed. The most important reasons for unwanted chemical reactions were found to be:

- impurities, contaminations, stray catalysts (20%)
- mixing of wrong chemicals (19%)
- mischarging, incorrect process conditions (19%)
- insufficient mixing (13%).

As expected, accidents in batch reactions were more frequently observed than those in continuous process plants, 57% and 10% respectively. A remarkable result was a high accident rate for holding or storage, 24%.

The secondary causes of the accidents could be classified in four groups:

- insufficient knowledge (34%)
- design error (32%)
- procedure error (24%)
- operator error (16%)

In related work the four types of unwanted chemical reactions also were found to be of great importance. Here too a basic lack of proper understanding of the process chemistry and thermochemistry was pointed out to be one of the main problems.

A question which is difficult to answer is: to what extent are the existing methods (risk analysis, laboratory tests) in general used by the plant managers/designers in the chemical industry today and in the past? Therefore, it is difficult to conclude if the existing methods are:

- sufficient but non-operational
- insufficient.

But the analysis of the accident case stories seems to point out that there is a need for:

- better information about and greater use of existing methods to determine thermal stability of single substances and mixtures
- improvements of thermal stability tests
- greater use of and perhaps improvements of risk analysis methods
- better training and education of operators.

3. ENERGY-ECONOMY MODELS

The modelling activities of the Energy Systems Group cover a wide variety of model developments. Simulation models have been developed for calculations on national or local levels. Methods to incorporate uncertainties in economic calculations are being developed. Furthermore, the group participates in the energy modelling programme of the Commission of the European Communities.

The models are intended to complement each other, and thus more models have been used in combination in specific studies. One aim of the group is to develop a span of models covering the sectors and technologies of the Danish energy system.

3.1. European Commission energy-economy models

The Energy Systems Group is responsible for the Danish implementation of a number of energy models developed within the energy-modelling programme of the Commission of the European Communities. The models presently under development are the macro-sectoral model HERMES and a long-term energy demand model MEDEE3. During 1985 work on these models was continued at a somewhat reduced level, due to lack of funding.

The HERMES-model is an econometric medium-term model determining the economic development and the impacts of changing energy prices in each of the EC-countries. As new fundings for the development of this model are expected for 1986, work in 1985 was limited to maintaining the status of the model and preparing a restarting of the project. This has included attending a status meeting in Brussels, some updating of the database, and a few estimations of equations. Further work to obtain the first simulations with the model includes estimating import and export equations, formulating identities, and implementating a simulation software.

The MEDEE3-model is a highly disaggregated and fairly technical long-term energy demand model that gives scenarios for developments in energy demand over a period of 25 to 30 years. During 1985 work on this model has been concentrated on application of the model to Danish conditions. The Ministry of Energy in particular has shown some interest in using the part of the model that

determines the energy demand for transport purposes for energy planning. A main part of the work has therefore been devoted to adjusting this part of the model, so that Danish transport data can be used as input. Another part of the work has been devoted to elaborating other parts of the model formulation with special emphasis on energy demand in industry. Further, the database has been updated and the base year of the model has been changed to 1980.

Finally, it should be mentioned that work on the development of an European version of the Danish Energy System (DES) model was started by the end of the year (see Section 3.3).

3.2. Uncertainties in energy economic calculations

Uncertainties in data in energy economic assessments are often dealt with through a number of sensitivity analyses or scenarios. This approach does not quantify the probability of different outcomes, and it may be difficult to overview the consequences of interaction between uncertain variables. Thus, the calculations do not supply the best basis for assessing the economic risk related to a decision.

Applying probabilistic methods, powerful tools can be developed to calculate overall consequences, including probabilities of many interacting and uncertain variables.

A project is carried out aimed at developing methods and modelling tools that incorporate uncertainties in energy economic analyses. Models that allow the direct introduction of distribution functions on variables have been developed, and thus, a broad basis of information can enter the assessments.

Probabilistic calculations displaying the total probability function provide the decision maker with an information platform that allows project evaluation from different decision criteria involving a basic attitude to economic risk.

The models combine the probabilistic calculations with sensitivity analyses on all stochastic variables. Sensitivity analyses describe the influence on the resulting overall uncertainty from individual data distributions, and thus point out major and minor risk contributing factors. Data and results from the models are presented graphically.

In stochastic models it is often assumed that the variables are stochastically independent. However, energy economic calculations often involve stochastic dependencies. An example occurs when the decision maker wants to take into account the assumption that high investment costs for an energy technology are correlated predominantly with long lifetimes and/or a high performance.

To overcome the limitations originating from the assumption of uncorrelated stochastic variables a method and easily handled procedures have been developed to open up the possibility for the decision maker to formulate stochastic dependencies between data variables.

Research in the field is ongoing. In 1985 work has been carried out on Phase I of a contract with the Nordic Council of Ministers. At present work is continuing on Phase II of this project.

3.3. Simulation models for the Danish energy system

The DES-Model (Danish Energy System) is a model system for translating energy demand forecasts into annual primary energy requirements, energy system costs, and selected environmental consequences.

The model describes a system of energy conversion units that connects the demands for various types of useful energy through intermediate energy products to the requirements for various types of fuels (Fig. 3.1). Each of these elements is described by types of energy input and output, capacity efficiency, investment and operating costs, and emission factors for pollutants.

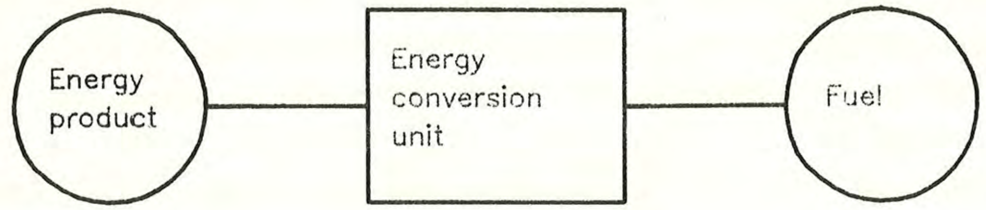

Fig. 3.1. Energy conversion unit.

A network of energy conversion units is built up consisting of the most important categories of conversion units and the most important energy flows between the demands for useful energy, intermediate energy products, and primary requirements. This is illustrated in Fig. 3.2.

An important feature of the energy system is that most types of energy demand can be satisfied from several sources. The most obvious examples are electricity and district heating. For these competing conversion units a merit order is specified, which leaves some types of conversion units as residuals. The outputs from these residual conversion units will be essential for evaluating the feasibility of the simulation results. The power system with combined heat and power generation (CHP) is the most important subsystem of competing units. The variation in the power demand is described by half-year load duration curves, and the generating units are scheduled in merit order according to their variable cost. The results of the simulation will be the annual electricity and heat output for each unit or type of units, and the fuel and operating costs of these units. These results are aggregated into groups of units characterized by fuel type, CHP-supply, flue gas desulphurization facilities (FGD), etc.

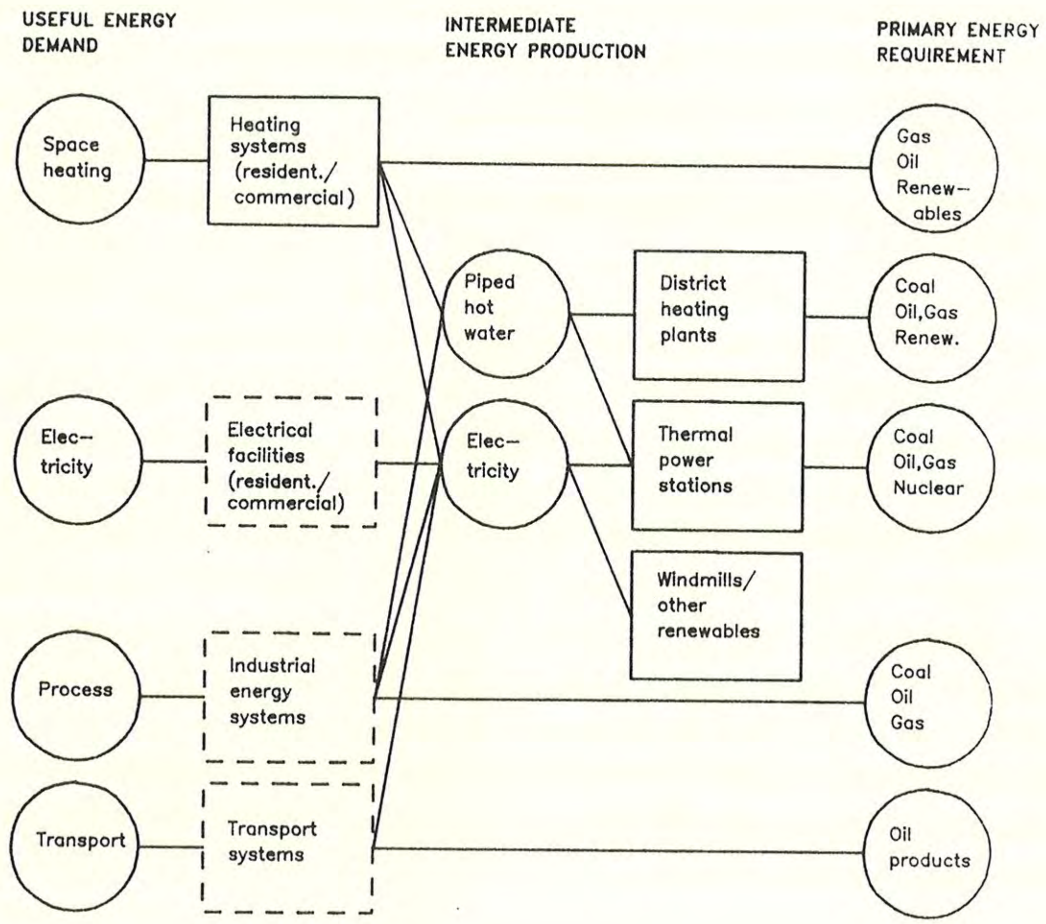

Fig. 3.2. The energy flows of the DES-Model.

A more thorough simulation of the CHP-system, which takes into account the simultaneous variations of the power and heat loads, is done by the Simulachron model. In this model load dispatch among the available units is simulated for a number of short periods (e.g. 3 days) with different demand variations for electricity and heat loads. These variations are given by two-hour time steps. A year is composed by an appropriate selection of short periods representing seasonal demand variations and variations in the available generating capacity.

The DES-Model has been used for several years as the most comprehensive model for the Danish national energy planning. It has also been used for several partial studies of the energy system,

e.g. the economic assessment of nuclear power, the environmental consequences of energy system changes, and scenarios for long-term consequences of the technological development. Simulachron is a tool for evaluating development plants for the CHP-production system on a national level; it can also be used to evaluate the introduction of new technologies to the system, or to estimate the more aggregate parameters of the DES-Model and to verify its results.

In 1985 the DES-Model has been improved by a more systematic treatment of renewable energy installations and other small-scale energy conversion units, and by the introduction of power stations with FGD facilities. New descriptions of the model are under preparation for use of the model in the Danish Energy Plan 1986 and for the development of an European version of the model.

The method developed for the economic assessment of nuclear power in Denmark (Ref. 6) using the models to evaluate the competitiveness of nuclear power in a power system with a substantial amount of coal-fired CHP is described in an article that has been submitted to an international journal. This subject and the method are of interest for the assessment of any large-scale introduction of very capital intensive power generating technology, e.g. wind turbines, or the introduction of CHP into a power system that already includes nuclear power.

The software of the DES-Model is a FORTRAN-program developed in the early 70's, and modified during the use of the model. A transcription of the program, to FORTRAN 77 was nearly completed by the end of the year. This will improve the portability of the model to other computers and thus the use of the model for other countries.

3.4. Simulation model for collective combined energy systems

The utilization of local energy resources has a high priority in the Danish energy plan. Many of the systems using these resources will be built as collective plants producing electricity and heat for district heating systems in smaller towns. There is a tendency for the systems to become increasingly complex, including technologies using several different energy resources.

The demand for electricity and heat as well as the energy content of the local energy sources such as wind and solar has a strong time variation. The highest value of the energy production from the combined collective energy systems is obtained if it is able to follow the time variation of the energy demand.

In order to test different control strategies and find an economical optimum system layout it is essential to make a simulation with short timesteps of the operation of the system. A model able to perform the simulation of such systems has been developed under contract with the Danish Energy Agency.

A model-diagram is shown in Fig. 3.3. The first inputs are time series for insolation, ambient temperature, standard wind speed heating, and electricity demand.

The standard wind speed time series is transformed into the actual time series by a wind atlas program using local surface roughness and turbine hub height as inputs.

The user has to specify technical and economic parameters for each technology in the systems to be analysed. In the system and operation strategy input the combined energy system is defined as a set of these technologies. The operational strategy for each unit is given by a logical expression. The last input is time series for the different fuel prices.

In the simulation the different units operate in every timestep in accordance with the control strategy. After the simulation over a year the model will calculate the net present value for the system on the basis of the investment costs, the operational and maintenance cost for the different units and the calculated fuel costs.

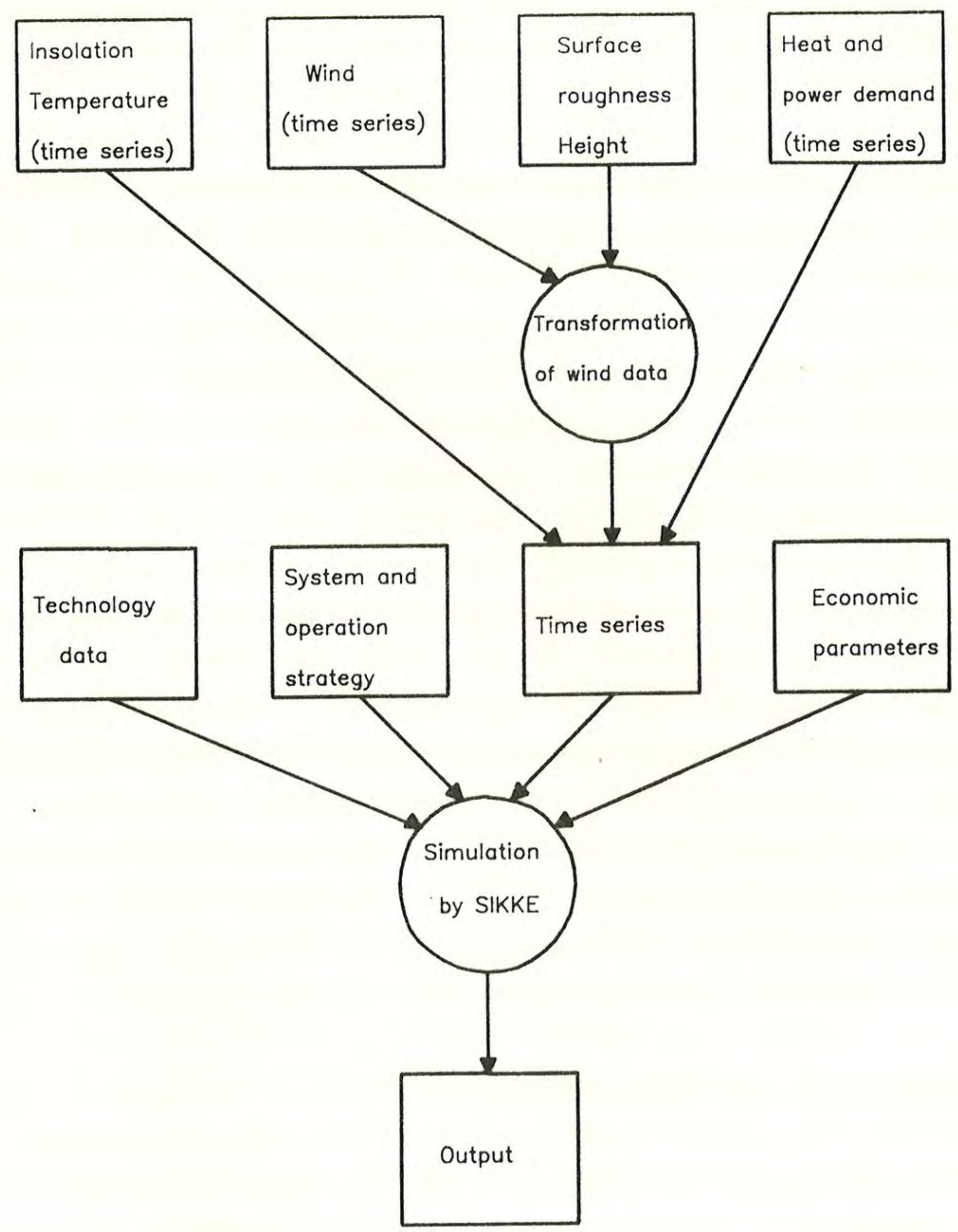

Fig. 3.3. The SIKKE-Model.

At present the model includes 14 technologies; it is planned to expand the model with additional modules representing solar cells and electricity storage. A special version of the program is being used in connection with the project on energy planning in developing countries (see Section 5.5).

4. RISK ASSESSMENT

During 1985 the Risk Analysis Group was engaged in several risk and safety analyses on a consultancy basis for industry and authorities.

A major project concerned the risk assessment part to be included in the guidelines for the implementation of the Seveso Directive in Denmark. This implementation has resulted in a growing demand for risk analyses of industrial plants.

The activity on oil and gas production in the North Sea has increased and several safety analyses were performed for platforms in the Danish as well as in the Norwegian sector. These works were performed as a subconsultant to Danish consultancy firms.

Finally, risk analysis was used as an aid in decision making concerning alternative connections (i.e. bridge, tunnel or ferry) across The Great Belt.

4.1. Offshore oil and gas production

The Rolf Development Project is a small unmanned, remotely controlled platform in the Danish sector. The platform is of the steel jacket type. The unstabilized oil and gas is transported through a 17 km long pipeline to the GORM-C platform for processing, and gas is sent through a separate pipeline for gaslift.

The analysis was performed in collaboration with COWIconsult and according to the Norwegian Petroleum Directorate's proposed regulations. The evaluation utilizes the event three methodology for identification of accident sequences and calculation of the probabilities of the residual accidental events. The consequencies of accidents like blow-outs, riser leaks and fire and explosions were modelled and evacuation possibilities were assessed.

Elf Aquitaine Norge A/S has prepared a concept for the development of the East Frigg Field comprising two gas reservoirs. The major elements of the concept are three subsea production stations, a subsea manifold station where the gas is gathered, a pipeline for transporting the gas to the existing TCP2 platform at the Frigg Field and "tie-in" installations on the TCP2 platform. At TCP2 the gas is treated, metered and compressed before it is exported.

On behalf of Elf Aguitaine Norge A/S COWIconsult, and Risø National Laboratory have worked out a safety evaluation of the proposed installations. This safety evaluation was submitted to the Norwegian Petroleum Directorate (NPD) in connection with an application for approval of the development project.

Due to the fundamental differences between the subsea East Frigg installations and the tie-in installations at TCP2, a separate safety evaluation was performed for each of these main sections. Both evaluations were performed in accordance with the principles laid down in the proposed regulations of NPD (Regulations for Safety Evaluation of Conceptual Design of Installations for Petroleum Production on the Norwegian Continental Shelf).

For the subsea installations the safety evaluation - performed by COWIconsult - covered the drilling, completion, installation and production phases as well as intervention on the subsea installations and three types of hazards were considered:

- Hazards to humans present on a vessel lying above the installations. The hazards considered are hazards due to release of hydrocarbons, e.g., blowout.
- Loss of production/major damage, e.g., due to external impact, extreme environmental impact, or blowout.
- Pollution of the environment.

The main elements of the tie-in facilities at TCP2 comprise a new module with equipment for gas/liquid separation and metering and an existing gas riser in one of the platform-supporting columns.

For the tie-in installations the safety evaluation - performed by Risø - covered the production phase with the main emphasis placed on hazards to human life. Thus, it was evaluated whether unfavourable event sequences, following major leaks in the tie-in installations, might lead to unacceptable damage to main supporting structures, shelter areas or to blockage of escape routes.

The accident events which were evaluated with respect to consequences and probabilities, included, for instance:

- Explosion in the column.
- Fire at the column top stemming from a riser leak or a leak in an emergency shutdown valve.
- Fire/explosion originating from leaks in the new module.

The safety evaluation of the proposed concept for development of the East Frigg Field has been approved by the Norwegian Petroleum Directorate.

4.2. Risk analyses for the chemical industry

The new environmental legislation has resulted in a number of risk analyses for the chemical industry. These industries, all falling under the "Seveso Directive" - are committed to the preparation of detailed risk analyses for their hazardous activities.

The risk analyses performed by Risø have focused mainly on the evaluation of the acute risk introduced by the plants to their immediate neighbours. The safety of the workers as well as long-term consequences of accidents to the environment have not been an object of the analyses.

In 1985 Risø has performed:

- a preliminary risk analysis of a fertilizer-producing facility, including among other things storage of cold and pressurized ammonia and ammoniumnitrite, nitric acid and sulphuric acid plants. The analysis was aimed at the identification of possible major accidents,
- a risk analysis in connection with the design of a plant for pesticide synthesis, the synthesis involving extremely hazardous chemicals. Both process, storage faciliters and handling procedures were considered. The outcome of the analysis was a number of recommendations for minor as well as more substantial plant modifications, all leading to a considerable improvements in plant safety,
- an accident analyses of a proposed hazardous waste treatment plant. The consequences of selected scenarios leading to serious acidents were evaluated. The analysis was not intended to be a comprehensive risk assessment of all accidents that could occur at the site. Rather, the scenarios represented accidents which could occur during handling of the waste once it had arrived at the site.

4.3. Traffic systems

In connection with the initial decisions about the design of some planned fixed road connections between Danish islands Risø has performed risk assessments an alternative solutions, i.e. tunnels, bridges, dams.

Together with COWIconsult Risø has been working as a consultant for Rowe Research and Engineering Ass. on a risk analysis of alternative fixed-road crossings over the Great Belt. The analysis was ordered by the Office of Public Works. The contribution from Risø consisted of procurement of background material, among which were regulations as well as statistical data concerning the amount and composition of hazardous goods transported across the Belt.

4.4. Implementation of the Seveso Directive

The Council Directive on "Major Accidents Hazards of Certain Industrial Activities" was passed in June 1982 (82/501/EEC). The directive orders the member states to assure its implementation adjusted to existing national legislation.

By tradition, inspection and control of industrial activities with respect to worker safety are performed in a decentralized manner. Environmental protection and emergency planning, on the other hand, are performed centralized. This emphasizes the need for close coordination and collaboration when implementing the directive.

Accordingly, the National Agency for Environmentalt Protection and the Directorate for Worker Safety jointly have published a comprehensive guide. The risk analysis group was involved in this task as consultant. The guide is intended for use by several parties. The local inspector and authority, persons in the central industries and agencies involved in evaluation of risk assessments and the industry supplying these assessments.

The guide covers the following areas:

a. Implementation of the directive with respect to legislation concerning

   - environmental protection
   - worker safety
   - emergency planning.

b. Administrative procedures followed by the public authorities.
c. Notification concerning hazardous industrial activities and substances.
d. Inspection of the hazardous industrial plants.

Furthermore, an appendix containing a alphabetic listing of all relevant substances and an appendix describing the contents of a risk analysis are included.

The importance and the necessity of a cooperation between the authorities are underlined throughout the guide, and guidelines for mutual exchange of information are given.

The directive explicitly describes the plants which have to submit an analysis to the authorities. If a plant produces or stores several substances listed in the directive but in an amount less than the corresponding limits specified, it is furthermore suggested that an evaluation of the safety of this plant shall be provided, if the sum of the relative amounts is greater than 1, i.e.

$$\frac{\text{amount}_1}{\text{limit}_1} + \frac{\text{amount}_2}{\text{limit}_2} + \cdots + \frac{\text{amount}_n}{\text{limit}_n} \geq 1$$

An appendix gives a description of the elements of a risk analysis. For each element the most important methods are described briefly, with references to supplementary literature and an example of application. The purpose of the appendix is to give an overview to persons at the authorities and industry, who have no prior knowledge of risk analysis. This means, that they will be able to identify the various parts of a risk analysis to be performed or reviewed, but obviously this is insufficient to perform an analysis.

The appendix describing the contents of a risk analysis has been written by Risø under the supervision of a steering group. The guide "Pligter ved risikobetonede aktiviteter", (ref. 7) (Duties in connection with hazardous activities) will be available in the beginning of 1986.

5. ENERGY PLANNING AND TECHNOLOGY ASSESSMENT

During 1985 ESG has been involved in a wide variety of projects within Energy Planning and Technology assessments. Among the most important in 1985 is the work carried out in relation to the new Danish energy plan, Energy Plan 1986. This work consists not only in participating in the working groups, but also in applying ESG-developed models, e.g. the model for energy consumption by industry.

Moreover, ESG has expanded its scope of activities during 1985. A newly started project concerns the development and implementation of models for evaluation of the Danish oil activities in the North Sea. ESG has been involved in an educational programme - Staff Training and Institutional Strengthening (STIS) - initiated by the Danish Energy Agency. The programme deals with the education of staff from developing countries; in autumn 1985 a group of Koreans participated in an 8-week course. Another minor job was a contribution to an European investigation on the cost of energy and primary materials caused by metal corrosion in the EC dealing with the potential energy savings from flue gas cooling.

5.1. Energy Plan 1986

In the late spring 1985 work on a new Danish energy plan, Energy Plan 1986, was started. A number of working groups were set up to study the aspects of supply and demand. ESG is represented in the following groups:

1) Energy demand forecasts and energy conservation
2) Heat supply
3) Electricity supply
4) Economic aspects of initiatives taken within the energy sector.

Moreover, the Energy Plan will treat the Danish oil activities in the North Sea in detail, as well as possible instruments for changing energy demand and supply.

ESG has been deeply involved in making the prognoses for energy consumption. Concerning process energy the newly developed model for the energy consumption for industry was applied. Given the assumptions for production and energy prices, the model forecasts industrial energy consumption, split into 13 branches and 4 fuel forms: solid fuels, liquid fuels, electricity and transport energy. The model is treated in more detail in Section 4.2.

The forecasts for transport energy are carried out in collaboration between the Ministry of Energy, the Ministry of Public Works and Risø. To study the consequences of different transport-policies ESG has applied the MEDEE-Model, implemented in Denmark by ESG for the European Commission.

The official forecasts for electricity demand are normally made in collaboration between ESG and the Danish Energy Agency. Concerning the domestic consumption of electricity ESG has developed a stock-vintage model - given the economic assumptions it forecasts the long-term demand for electricity for household applicances. The use of electricity in the commercial sector is due to its heterogenous character very difficult to forecast. In 1984 ESG initiated a project in collaboration with the Energy Agency to investigate the demand of electricity in the tertiary sector (see Section 5.3). Preliminary results of this survey are used to forecast electricity consumption in the commercial sector in Energy Plan 1986.

The supply groups in Energy Plan 1986 have just started their work. It is expected that the Danish Energy System-Model (DES-Model, described in Section 3.3) will be used to calculate the consequences of a number of supply scenarios. The final Energy Plan 1986 is expected to be published medio 1986.

5.2. A technical-economic model for energy consumption by industry

This model is developed for the Ministry of Energy and is used as a forecasting tool in national energy planning. Work on the model was started in January 1984 and the first forecasts using the model was obtained by the end of 1985.

The general structure of the model is shown in Fig. 5.1. At the top the macro-economic model ADAM is found. This model is used by the Ministry of Finance to forecast the economic development and operates with six industrial branches. As these six branches are very inhomogenous when looking at energy, a fairly simple split-model is used to devide the six branches into 14 more energy-homogenous branches. For each of the six branches the more energy-intensive sub-branches are simply separated. Finally, an energy model converts forecasts for the economic - and the energy price development into forecasts for the energy consumption by each of the 14 branches and the four fuels: solid, fluid, electricity and transport fuels.

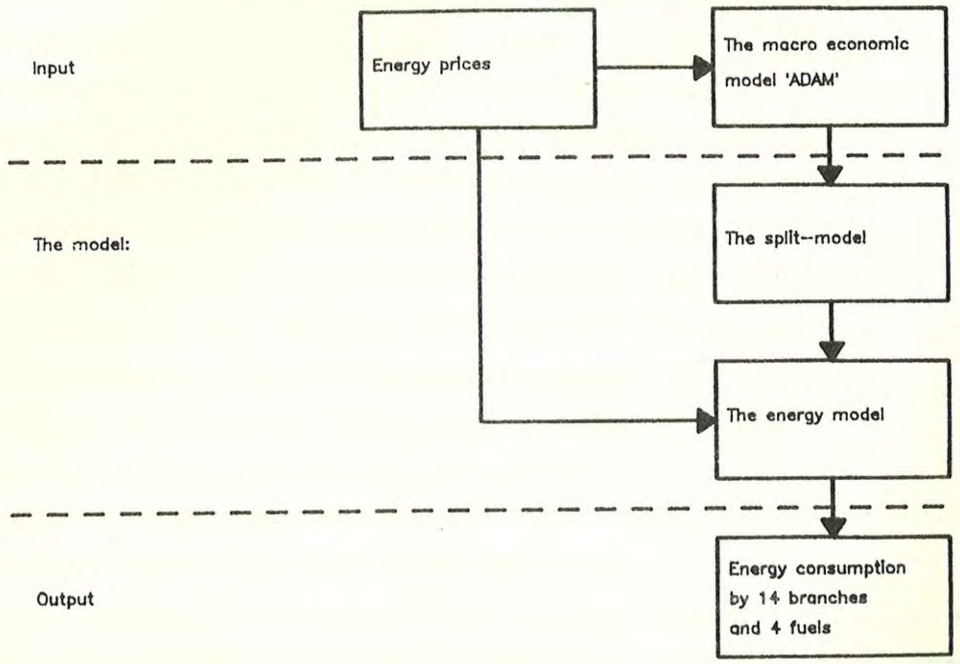

Fig. 5.1. The general structure of the model.

In order to build the model the development since 1966 has been analysed, and, to explain the development for each of the branches and fuels, both technical and economic factors have been considered. The most important economic factors are changes in the level of production, real energy prices, employment, and investment. Of important technical changes one might mention the introduction of new production techniques or processes and the starting up or closing down of specific production inside the individual branches. As most of these technical changes alter the level of the energy consumption by one stroke they are represented in the model by dummy-variables, i.e. the historical

development is corrected for one-time changes by 0-1 variables. What is obtained by this is that historical one-time changes are not implicitly reproduced in the forecasts and that future one-time changes have to be considered explicitly.

The main conclusions from the historical analysis are that substantial differences exist between the branches and that a major part of the energy savings are obtained by structural changes and by closing down some of the more energy-intensive productions inside the individual branches.

Concerning the mathematical specification of the model quite a number of alternatives have been tested. The principally different top-down and bottom-up approaches have been especially tested and the preferable approach for each branch has been chosen for the model. In the top-down approach an equation for the total energy consumption by the branch is estimated, and this total is distributed among the fuels using a cost share system. In the bottom-up approach an equation for each fuel is estimated, and the total energy consumption by the branch is calculated as the sum of the fuels.

In total, the model contains about 60 estimated equations plus quite a number of identities. The equations for the individual branches are very different both concerning the approach preferred, the variables included, and the nummerical size of the coefficients and elasticities. On average for the industry as a total the model gives a production elasticity of about 0.7 and an energy price elasticity of about -0.3. Using production and energy price forecasts from the Ministry of Finance, the forecasts of the model are given in Fig. 5.2. Looking at this figure the energy consumption is expected to grow faster than production up till 1990 and after 1990 slower than production. The main reason for the increasing energy coefficient up till 1990 is that some of the more energy-intensive branches are expected to grow faster than average for the industry.

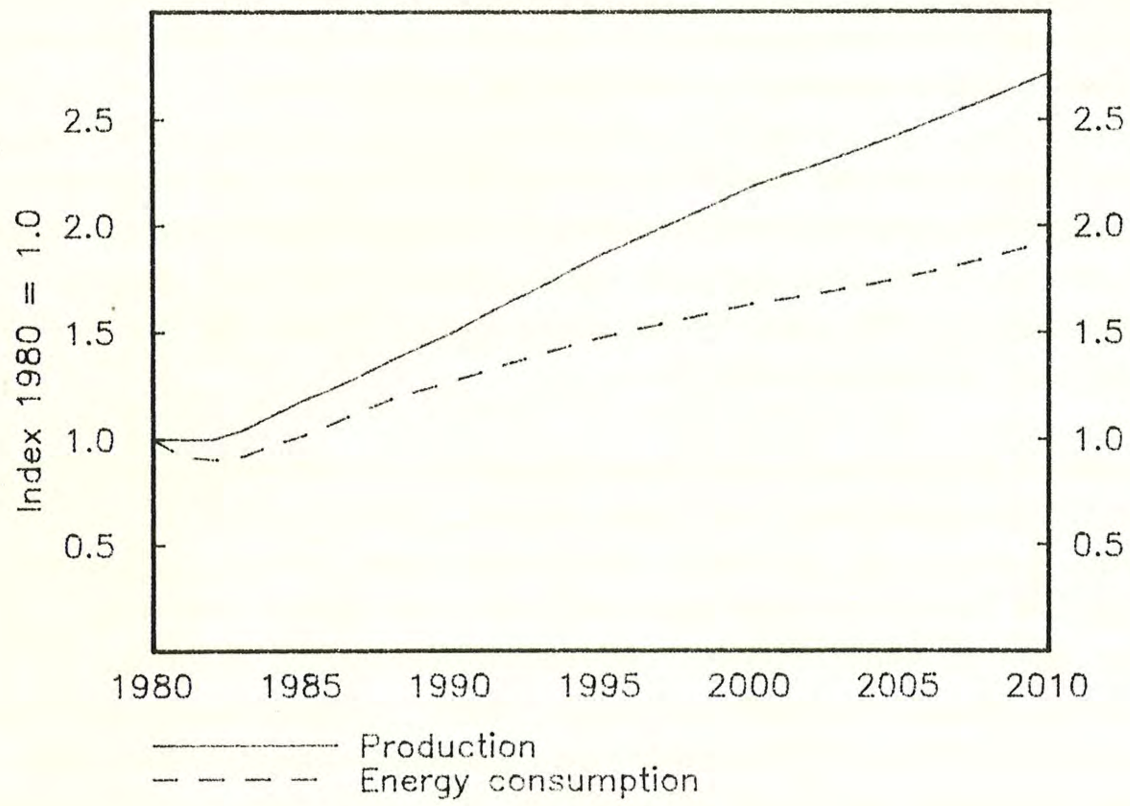

Fig. 5.2. Forecasts for industrial production and energy consumption.

5.3. Electricity demand in the commercial and service sector

The commercial and service sector consumes a little less than one third of the total electricity consumption in Denmark, or 6.5 TWh in 1984. The split between the main categories is shown in Fig. 5.3. The share for public consumption has increased slightly, while the private service sector has increased its share very much, from 20% in 1978 to 23% in 1984.

The project is carried out in collaboration with the Danish Energy Agency. The aim is to investigate the structure and development of electricity demand in the commercial and service sector.

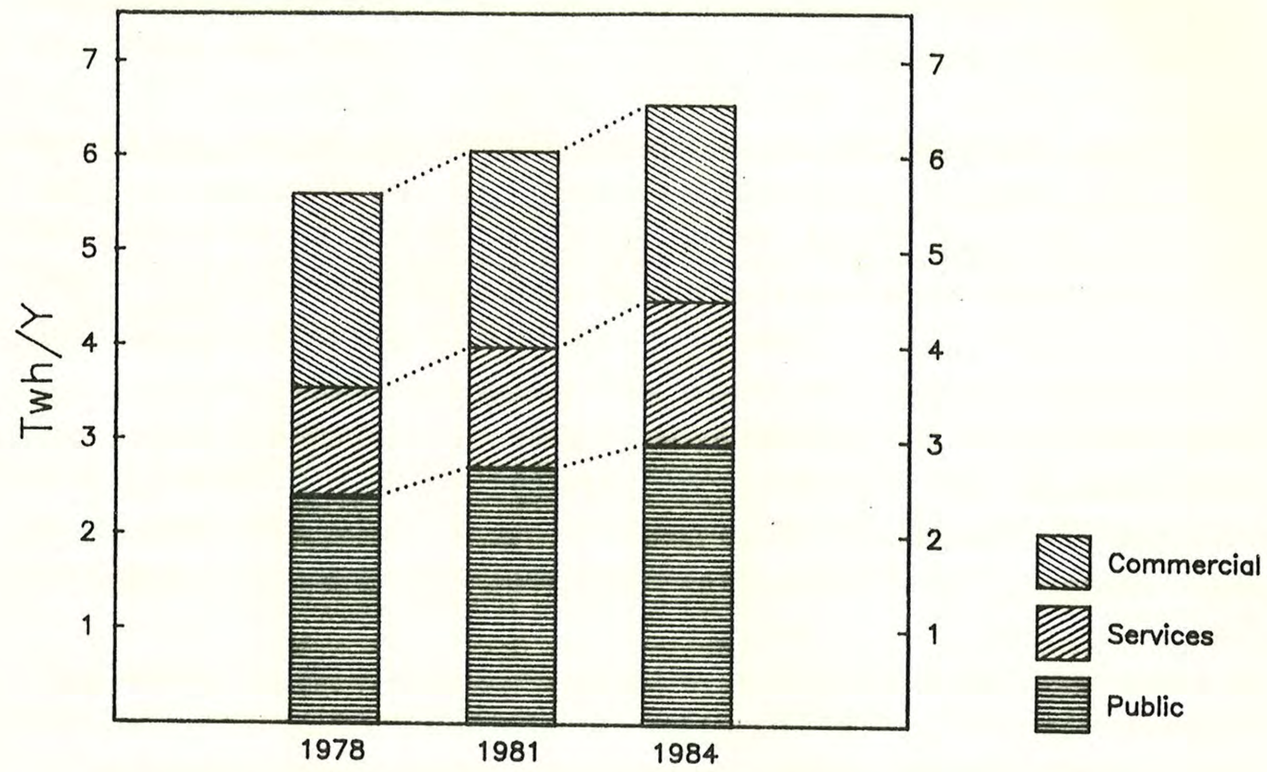

Fig. 5.3. Total consumption of electricity in the commercial and service sector, TWh.

The consumption of electricity in the commercial sector is heavily related to retail trade, especially shops selling everyday commodities and food. For the last mentioned group more than 50% of total shopping area is covered by the survey. The key data are annual electricity consumption in physical terms and the related shopping areas, taking special electricity using equipment into account. The statistical data are mostly collected from large shop chains.

The public service sector is described by collecting data from municipalities, counties, large institutions and offices. The data are split into categories depending upon the function of the building: schools, hospitals, kindergartens, etc. Table 5.1 shows the consumption of electricity in the various institutions of a county. Not surprisingly, hospitals are found to be the most important single category. For that reason a questionnaire is sent to all hospitals in Denmark. More than 75% have responded to this questionnaire.

Table 5.1. Consumption of electricity in county institutions in a country, 1983.

	MWh	m^2	kWh/m^2	Standard deviation
Hospitals	7,340.0	68864	106.6	7.4
High schools	2,031.4	49015	41.4	17.5
Day and night inst.	705.3	16835	41.9	19.6
Rest homes	360.7	8201	44.0	13.0
Administration	597.6	7959	75.1	37.0

The private service sector is the most inhomogeneous category, and here especially some work remains to be done. A final report on the survey was prepared at the end of 1985.

5.4. Energy rationing model for acute energy shortages

The purpose of the project is to analyse the possibilities for an optimal allocation of scarce energy resources in the event of a short-term reduction in energy supply. The analysis involves the consideration of, for example, strategic reserves and rationing. The result of the study is a model which can be used to decide on the optimal allocation of energy resources according to a set of criteria defined by the user.

To be useful as a planning tool an energy-rationing model in practice has to operate on a highly disaggregated level, and therefore, detailed information is needed about the various sectors in the economy and the different demand categories. The official Danish input-output tables and energy matrices, which are published by the Danish Statistical Office, are the main sources for this detailed data information.

This is a Ph.D. project carried out in collaboration with the Institute of Economics at the University of Copenhagen, and it is almost completed.

The energy rationing model: LINRAT, is an input-output model in which an object function is optimised under given constraints by the method of linear programming. As the energy shortage is assumed to last a short period, the technical coefficients in the model can be assumed constant.

The object function is flexible and therefore it is possible to specify alternative linear combinations of criteria in collaboration with the model user. In the present version of LINRAT the aggregated employment in the economy is maximised.

The constraints in the model are incorporated in four modules: an input-output, refinery, substitution, and energy rationing module.

The input-output module is a disaggregated account system for non-energy flows and total energy flow in the Danish economy. The main aim of the refinery module is to establish a connection with some flexibility between the quality of the crude oil and the mix of refined products. Substitution in the short run between alternative energy products is possible in the substitution module which further comprises the detailed energy balances. An energy rationing scheme is implemented in the energy rationing module. In the present state LINRAT comprises 14 non-energy sectors, 3 energy conversion sectors and 8 energy products. Compared to the official Danish 117 input-output sectors the non-energy sectors are aggregated, the energy conversion sectors are identical, and the energy products are disaggregated. The latter ones are based on the detailed energy matrices.

LINRAT is implemented on the central Burroughs computer at Risø. Test runs have been performed with promising results. The model is able to generate a reference scenario that reflects the undisturbed economy, i.e. the economy without acute energy shortage, as well as different crisis scenarios showing alternative mixes of policy instruments responding to different combinations and sizes of acute shortages on imported crude oil and refined products.

The Ph.D. project will be completed early in 1986 at which time a report documenting the model will be issued.

5.5. Energy planning and project assessment in developing countries

Based on the ESG's experience in energy planning and technology assessment from Denmark and the European Community, the first activities related to energy planning in developing countries were initiated in 1984. These activities were continued in 1985 and new projects were started.

A Ph.D. study concerning new energy technologies and assessment methods applicable to energy projects in rural areas was started in 1984. The project is performed in collaboration with the Technical University of Denmark, and the Department of Energy (DOE) in Zambia.

A visit to Zambia took place from mid April to late June. (Funding was provided by the Danish Council for Scientific Research and Risø).

The purpose was to collect data for the project and to obtain the necessary insight in the rural society both in general and in particular within the energy area. Together with a Zambian engineer from the Rural Energy Development Section of DOE the main task was to perform a small energy survey in the rural district of Zambezi in the north-western part of Zambia. Data was collected on energy consumption (wood, charcoal, kerosene, and electricity), energy production and available local and renewable resources.

The data and the general insight into the rural society will be used as basis for selected cases in the Ph.D. project, and in DOE

as a first reference for the rural energy planning activities.

The Ph.D. project has continued with a study of existing methods for project appraisal, and their use in both multilateral organisations like the World Bank, ILO, E.C. etc. and national aid agencies as Danida, SIDA, NORAD. The final aim of the project is to establish a methodology that can be used, e.g. in DOE for planning and assessing new energy projects especially for rural areas.

Another activity that started in 1984 was a project on developing countries and their environment exemplified by the depletion of wood resources in Tanzania. The project was initiated by the Danish Ministry of Environment. ESG participated in the project looking at the energy aspects related to availability of fuelwood and charcoal. The work was finished in December 1985 with a report and a conference sponsored by the Ministry. (Ref. 8).

In December 1985 an assessment of the wind energy potential and economic viability of wind turbines in the power system on Cape Verde was initiated. The Department of Meteorology and Wind Energy at Risø is responsible for the project to the United Nations Development Programme (UNDP), the funding agency. ESG is doing the energy systems analysis and the economic evaluation.

Probably the most interesting new activity started in late-85 is the engagement in a large project called "Energy development: Fuelwood". The project is performed for the SADCC Energy Secretariat (SADCC stands for South African Development Coordination Conference; the member states are Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia and Zimbabwe) and is financed by the European Community and the Dutch Government. The project group consists of three companies from Holland and Great Britain, ESG from Denmark and a number of individual experts from various countries. ESG will mainly be working with woodfuel energy models and methodologies, and this may also include methods for assessing woodfuel-related energy projects.

5.6. Wind energy

The economics of wind turbines and long-term simulation of wind/diesel systems were the main activities in relation to wind energy in 1985.

Together with the Test Station for Windmills, an investigation of a windpark consisting of eight 95-kW wind turbines was made for the Municipality of Roskilde. Four possible sites for the windpark were found. Using the wind atlas method the early electricity production in the windpark with medium wind resources was found to be 168 MWh. The total costs of the projected windpark were found to be about 6 million Dkr.

Assuming constant energy prices, the net present value as seen from the municipality was positive using a discount rate of 5%. The effect of this investment on the Danish balance of payment would be positive since it would take only 3 years to repay the first import.

The long-term simulation model SIKKE (see Section 3.4) is now operational. It will be able to evaluate the economics of different system layouts and different control strategies by a simulation over the year with time steps such as 10 min, or 1 hour. Both the diesel generator and wind turbines modules are now included, but different electricity storage modules are not yet incorporated in the model.

As an example of the structure of the electricity demand in a small community without grid-connection the island of Anholt (in Kattegat) is being analysed. The load has been logged using a mechanical chart recorder. The 1984 data was digitised with a timestep of 10 minutes. These data are now being analysed on the computer together with a series of measurements of the load with timesteps of 1 second taken by the Test Station for Windmills at Anholt the 2nd week in March 1985.

5.7. Ocean energy

The Danish Ministry of Energy is sponsoring an investigation entitled: "Potential Possibilities for Ocean-current Power Production". It comprises a critical literature review, a global search for energy-intensive ocean-currents, an analysis of the introduction of a hypothetical ocean-current power plant into a local energy system and a feasibility study of a power plant in a chosen ocean-current. On a consultancy basis ESG has undertaken the critical literature review and the study of the introduction into a local energy system.

The literature study has shown that very little original work has been reported as most of the papers are overviews relying heavily upon a few papers from The MacArthur Workshop in 1974 where a 168-m diameter turbine for the Florida current was proposed. Even less experimental work is reported. In fact, only two tests are found, one with a 100-cm diameter rotor in a test channel and one with a 30-cm diameter rotor in East River, New York.

The international research in this field is very limited. Apart from this Danish investigation there have been no programmes outside the USA. This lack of interest is attributed to the very small global potential. This is in line with the Danish global investigation performed by Dansk Hydraulisk Institut which found only two really interesting locations with high current velocity. Both were tidal currents and one of them was Vestmannasund in the Faroe Islands, which was chosen as an example because the combination of high tidal-current velocities and an expensive electricity structure - partly based on diesel production - gives a renewable energy source such as tidal-current a more competitive position than perhaps anywhere else.

The Faroe Islands energy system was described, the value of a potential production was estimated and some conditions for the fitting into the system were evaluated but it was not considered in our study whether an ocean-current power station would be economical or at all technically feasible.

6. PUBLICATIONS AND LECTURES

6.1. Publications

J.M. Christensen: Energy Survey in Zambezi. Report from a study in Zambia - 1985. Risø-M-2553.

P.S. Christensen, J. Fenhann, N.A. Kilde, H. Larsen and P.E. Morthorst, Long-term prospects for new energy technologies and their introduction into the Danish energy system. The Fourth International Conference "Energy and Society", 9-11 September 1985, Inter-university Centre, Dubrovnik, Yugoslavia. 16 p. Available on loan at Risø Library.

Niels A. Kilde, Indpasning af et hypotetisk havstrømskraftværk i det færøske energisystem/Introduction of a hypothetical ocean-current Power station in the energy system of the Faroe Islands, Risø, December 1985, 37 p.

H. Larsen, Renewables and combined systems. The ninth annual international scientific forum on the silent energy revolution, 14-18 October 1985, Copenhagen, Denmark. 18 p. Available on loan at Risø Library.

H. Larsen, Trends in energy technology. Conference on technology transfer and licensing opportunities in the energy sector, 11-13 November 1985, Copenhagen, Denmark. 13 p. Available on loan at Risø Library.

P.E. Morthorst, Electricity in the public sector - a few examples for Denmark, Proceedings: International Workshop on Electricity Use in the Service Sector, March 18-20, 1985. EPRI P-4401-SR Electric Power Research Institute, Palo Alto, USA. 11 p.

P.E. Morthorst, Forecasting electricity demand for Denmark, Conference on Operations Research in the Energy Sector, May 13-14, Oslo, Norway. 10 p. Available on loan at Risø Library.

P.E. Morthorst, P.S. Christensen, J. Fenhann, N.A. Kilde and H. Larsen, Den teknologiske udviklings betydning for det fremtidige energisystem/Long-term prospects of energy technologies. Nordisk seminar on energiprognoser, 23-24 September 1985, Åbo, Finland. Available on loan at Risø Library.

P.E. Morthorst, Risø, and Ole Thorbek, Danish Energy Agency, Udviklingen i elforbruget i Danmark - er der tegn på mætningstendenser?/The development in electricity consumption in Denmark - are there tendencies towards saturation? Nordisk seminar om energiprognoser, September 23-24, 1985, Åbo, Finland. Available on loan at Risø Library.

6.2. Lectures

Frits Møller Andersen. Interfuel substitution models; Some results for Denmark. Meeting of Danish Econometric Society, Sandbjerg, 10-12 May.

P.E. Becher, K.E. Petersen, D.S. Nielsen and L. Schepper. Two days course in risk analysis for Rambøll & Hannemann, 6-7 September 1985.

Poul Erik Grohnheit. Environmental consequences of energy use. Meeting of Danish Econometric Society, Sandbjerg, 10-12 May.

Poul Erik Grohnheit. Calculations for Energy Plan 81, guest lecture in course on energy planning at Physics Laboratory III, Technical University of Denmark 4th October 1985.

Dan S. Nielsen. A risk analysis of Dansk Soyakagefabrik clorine production plant, courses for the Danish Agency of Environmental Protection and the Directorate for water safety. 22 October, 12 November and 10 December 1985.

Kurt Erling Petersen. The elements of risk analysis, courses for the Danish Agency of Environmental Protection and the Directorate for water safety. 22 October, 12 November and 10 December 1985.

Ellen Pløger. The Industrial Energy Consumption. Meeting of Danish Econometric Society, Sandbjerg, 10-12 May.

7. STAFF

Hans Larsen, M.Sc. in Electrical Engineering. Ph.D. in Reactor Physics in 1973. From 1973 to 1976 at Dragon project at AEE Winfrith, U.K. Risø from 1976. Energy Technology Department 1976-1980, working with systems reliability. Head of Energy Systems Group 1980-1984. Head of Systems Analysis Department from January 1985.

Energy Systems Group:

Poul Erik Morthorst, M.Econ. Economist specialised in econometrics and macro-economics. Risø from 1978. Main activities: General energy planning with emphasis upon forecasting electricity demand. Economics of renewable energy technologies, especially wind turbines. Head of Energy Systems Group from January 1985 and deputy head of department.

Jørgen Fenhann, M.Sc. Physicist with mathematics and chemistry as subsidiary subjects. Niels Bohr Inst. 1977. Risø from 1978. Main activities: Energy planning, economics of new and renewable energy technologies, energy planning for developing countries and computer simulation. Deputy head of Energy Systems Group.

Frits Møller Andersen, M.Econ. Specialized in econometrics and macro-economic modelling. Research assistant Århus University 1978. Assistant planner in a local government 1979. Risø from

1980. Main activities: Development of the macro-sectoral model HERMES for Denmark and a technical-economic model for the Danish industrial energy consumption.

Peter Skjerk Christensen, M.Sc. Elec. Eng. Risø from 1958. Nuclear research and education (1958-1968), reactor engineering and thermo hydraulics including simulation models (1969-1976), Energy Systems Group from 1977. Main activities. Energy systems modelling. Secretary for the steering group for R & D in coal combustion of the Ministry of Energy.

Poul Erik Grohnheit, M.Econ. Danish Building Research Institute 1969-71, town planning consultant 1971-72 and 1979-80, budgetting and economic planning at local government 1973-79. Risø from 1980. Main activities: Energy system simulation model, power system economics and environmental consequences of energy production.

Niels A. Kilde, M.Sc. Chem. Eng. The Danish Steelworks Ltd. 1962-81. Research and quality control (1962), planning and administration (1967), casting dep. manager (1972), development and energy manager (1977). Risø from 1981. Member of the steering group for R&D in industrial processes of the Ministry of Energy.

Helge V. Larsen, M.Sc. Elec. Eng., Ph.D. Technical University of Denmark 1974. Storno A/S 1975: development of VHF/UHF equipment. Risø from 1976. Department of Reactor Technology 1976-1977. Energy Systems Group from 1977. Main activities: CHP production, modelling of energy systems, economic models for the oil and gas sector.

Gordon A. Mackenzie, B.Sc. Ph.D. Guest researcher at Risø 1974-78. Edinburg University 1978-79. Energy Systems Group from 1980. Presently on leave from Risø and working as special advisor to the Director for Department of Energy, Ministry of Power, Transport and Communications in The Republic of Zambia.

Helle Trøst Nielsen, M.Sc. B.A. (French) Risø from 1984. Main activities: modelling of energy systems, analysis of time structure of power demand for small communities, renewable energy, experimental measurements on heating systems.

Lars Henrik Nielsen, M.Sc. Risø from 1981. Main activities: Probabilistic methods and model development, assessment of energy technologies, energy conservation, and forecast modelling.

Ellen V. Pløger, M.Econ. Specialised in economic modelling and econometrics. Worked in the Danish Statistical Office on national accounts, energy balances, and input-output models. Risø from 1982 until July 1985. Main activities: input-output analyses, and employment and import effects of energy technologies.

Sverrir Sverrisson, M.Econ. Risø from 1985. Main activities: macro-economics, econometrics and international economics, development and implementation of the CEC macro-sectoral model (HERMES).

Bente Villadsen, M.Sc.Econ. Specialized in economic modelling and operations research. Risø from 1984. Main activities energy demand simulation, methods for evaluating uncertainties in energy economic assessments, technical-economical modelling of offshore activities.

Risk Analysis Group:

Per E. Becher, M.Sc. Mech. Eng. Airforce Equipment Command 1970-71. Risø from 1971. Department of Energy Technology 1971-1984. Risk Analysis Group from 1984. Main activities: Structural reliability. Reliability and safety analysis of nuclear plants. Safety analysis of industrial plants. Head of Risk Analysis Group.

Kurt Erling Petersen, M.Sc. Risø from 1977. Department of Energy Technology 1977-84. Risk Analysis Group from 1984. Main activities: Development of computer codes for reliability analyses, models for mechanical components, and data collecting systems for reliability data. Deputy head of Risk Analysis Group.

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Postgraduate Students:

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